RADC-RAU-TM-63-2

GROUND-AIR-GROUND DATA TRANSMISSION SYSTEMS TESTS

Adolph J. Uryniak

TECHNICAL MEMORANDUM NO. RADC-RAU-TM-63-2

July 1963

Equipment Laboratory
Rome Air Development Center
Research and Technology Division
Air Force Systems Command
Griffiss Air Force Base, New York

465L System

FOREWORD

An expression of thanks is extended to Telesig Corporation, Radiation Incorporated, and Goodyear Aircraft for the use of their equipment. In addition, the assistance and contribution in the conduction of the tests and writing of this report by Mr. Earl C. Weaver of Hq. GEEIA was invaluable.

AIR FORCE, Canterbury Press, Rome, N. Y., 8/7/63, 124

ABSTRACT

Tests were conducted at RADC to check the feasibility of an Air/Ground/Air Narrow Band FSK Data System utilizing frequency diversity and doppler correcting techniques. Results of air/ground/air data transmission tests are described in this report. These tests were conducted between RADC's Ava Test Annex and a KC-135 flying to California and Alaska. The equipment at both terminals used narrowband frequency shift keying, with frequency diversity and doppler correction, in conjunction with equipment currently in Air Force inventory. In addition, a solid-state tape printer and a TDMS-5 sender were used. The teletypewriters were set to operate at 100 WPM (74.2 bauds/sec).

It can be concluded from the test results that doppler-correcting narrowband techniques applied to frequency diversity operation in ground/air/ground data transmission is feasible, resulting in reliability and error rates equivalent to ground point-to-point systems operating within similar effective power ranges and antenna gains.

PUBLICATION REVIEW

This report has been reviewed and is approved.

Adolph J. Uryniak

Approved: Adolph J. Uryniak

Approved: TODD G. WILLIAMS, LT COL, USAF
Chief, Equipment Laboratory
Directorate of Communications

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GROUND-AIR-GROUND DATA SYSTEMS TESTS

1. INTRODUCTION

The Air Force has a requirement for an air/ground/air high frequency data transmission capability. Attempts to fulfill these requirements in the past have generally proven unsatisfactory. Systems tried usually employed Frequency Shift Keying (FSK) and used a wide frequency shift to circumvent the doppler effects associated with high speed aircraft. The use of wideband information channels has not been satisfactory because its use degrades the signal-plus-noise/noise ratio, makes the circuit more vulnerable to interference from other stations in the channel, and uses valuable bandwidth which is becoming continually more crowded.

For narrowband FSK, automatic correction for doppler effect is essential. Another problem in air/ground/air high frequency systems, as in point-to-point high-frequency systems, is selective fading. This phenomenon is particularly detrimental in the Auroral Zone where fades occur at rapid rates with accompanying high absorption. To overcome this, diversity operation is essential for successful data transmission.

Many facets of the air/ground data transmission problem were checked before test plans were formulated. The following areas were considered:

a. If practical, the system should be compatible with existing USAF, Army and Navy point-to-point high-frequency systems so these could be used for air/ground service when necessary. This should be accomplished with a minimum modification or addition to ground equipments. The three services almost universally use the AN/FGC-29, the AN/FGC-60, and the AN/FGC-61 data transmission terminals for point-to-point communications. These are all compatible with each other and use multichannel narrowband frequency shift keying techniques. All can be used on either space or frequency diversity.

b. The system must use narrowband techniques to minimize noise and interference. Present point-to-point systems use this technique as outlined in "a" above.

c. Some type of diversity is essential to overcome the problem of selective fading. Space diversity cannot be used on the aircraft due to space restrictions and inability to effect the wide antenna separation necessary for adequate diversity improvements. Frequency or sequential (time) diversity are the main alternatives. Sequential diversity, to be effective, requires a higher rate of transmission speed (shorter baud lengths) and usually a storage matrix to store and compare groups of characters sent in different time periods. The equipment for doing this is costly. Furthermore, ionospheric characteristics require the length of each baud transmitted at HF to be at least several milliseconds long. Also, the sequential system is not compatible with existing military point-to-point systems. As a result of the complexity of sequential diversity and its doubtful advantages over other systems, frequency diversity was given prime consideration.

d. If narrowband transmission techniques were to be used, some technique for doppler correction should be provided.

e. Due to the possible application of an HF air/ground data link to a system such an an airborne command post, the link should be capable of furnishing more than one single data channel.

2. PROJECT PLANNING

The objective of the tests conducted at RADC was to check the feasibility of an air/ground/air data system using narrowband frequency shift keying with frequency diversity and doppler correcting techniques. This equipment was to be used with Air Force equipment currently in the inventory. In addition, a new solid state printer and a TDMS-5 automatic sender were incorporated into the test to check their operation at 100 WPM (74.2 bauds/sec).

The testing program was designed to include local and long range flights. One long-distance flight was planned to Alaska, the second to the United Kingdom, and the third to Australia. Figure 1 shows the proposed areas in which the flights were to be made. The first test flight following a hairpin path was planned from Eielson AFB into the Auroral Zone to within 400 miles of the North Pole, and the second flight was planned into the Auroral Zone from the United Kingdom, and the third flight was scheduled to be flown out of Sydney, Australia, to check the feasibility of the system at great distances. Because of bandpass limitations of the AN/ARC-58 airborne equipment and the AN/FRC-44 ground equipment, four channels in frequency diversity (eight tones) were tested.

A KC-135 aircraft was scheduled to provide as much doppler shift as possible. This permitted observance of the performance of the equipment in the presence of considerable frequency error. As a further test condition, the system was operated at 100 words per minute (74.2 bauds/sec) on a start-stop basis. Telesignal Corporation provided the doppler correction device and two four-channel frequency-diversity data transmission terminals.

Two terminals for test were submitted in September 1961. These were given preliminary laboratory tests and functioned satisfactorily. Installation work on the aircraft and ground station was started on 20 April 1962. (See Figures 2, 3 and 4).

3. TEST LIMITATIONS

Local flights with the KC-135 aircraft from RADC on 27 and 30 April 1962 were completed. In addition, the first long distance flight to Eielson AFB, Alaska, via Seattle was completed 1 through 5 May 1962. Because of difficulties in obtaining further flight approval for the KC-135 aircraft, plans for flights to the United Kingdom and Australia had to be abandoned. In their place, a flight to Travis AFB was made on 12 and 13 June 1962.

Several noteworthy limitations affecting the tests were as follows:

a. The ARC-58 was operated on low power since it is designed for intermittent radiotelephone use. Total average power was estimated between 75 and 100 watts when loaded with eight tones.

b. The TDMS-5 sender malfunctioned. However, it was possible to use single letters sent by the unit. It was augmented by a TS2B/TG (mechanical sender) on the second flight.

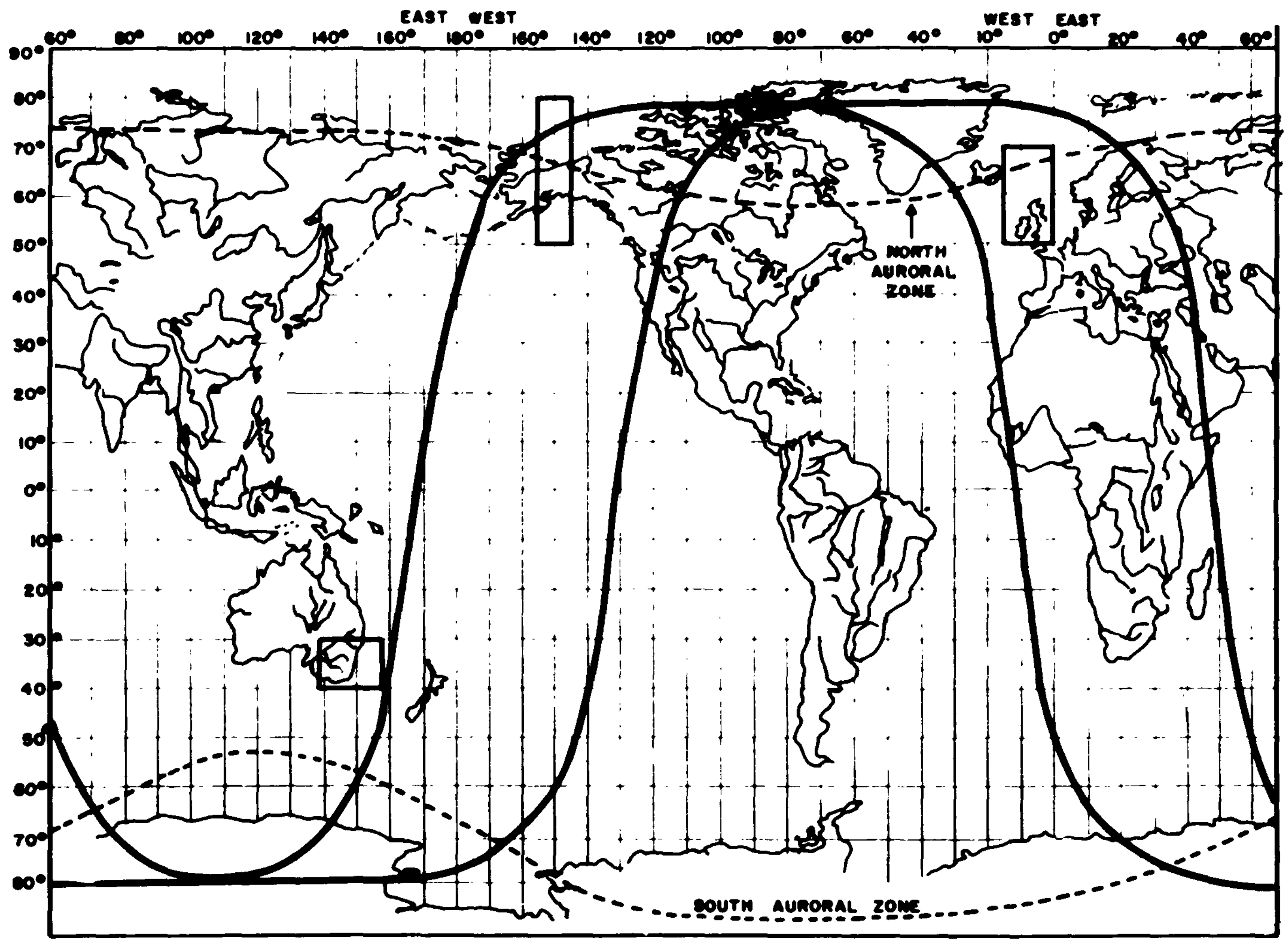


Figure 1. Flight Areas.

Figure 2. Aircraft Installation.

Figure 3. Aircraft Installation.

Figure 4. Aircraft Installation.

c. The Goodyear solid state printer functioned very well. One exception was tape legibility which was poor at times. This was probably caused by low moisture content in the paper tape.

d. During the second flight the M-28 teletypewriter in the aircraft was erratic.

The ground transmitter used in the tests was the AN/FRC-44. The antennas were a 2-11 mc Discone below 10 megacycles and a Log Periodic above 10 megacycles. Power output was adjustable and ranged from 2 kw to 20 kw average. Most of the transmissions were made using 8-10 kw average power output. High power (20 kw) was used on 1 May 62. This transmission was made "in the blind" from the Ava Test Site to the aircraft after contact had been lost from air to ground. Except for a short period, the aircraft received usable copy during all of this flight.

As mentioned above, flights were planned through the Auroral Zone to determine the problems of data transmission in this area. During most of the tests high absorption conditions prevailed as expected. Voice transmission was difficult during most of the flight tests. During reception at Ava on 3 May 62, when data was being received with comparatively low error rates, the normal voice transmissions were badly garbled and almost unintelligible due to the rapid auroral "flutter."

Except for a few transmissions, all four diversity channels were energized at all times in both directions. Data was passed on two channels simultaneously on about 85 percent of all transmissions. The aircraft contained two teleprinters, one M-28 Teletypewriter and one Goodyear solid state tape machine (see Figure 5). Two M-28's and one AN/FGC-52 teletypewriters were used at Ava Test Site. The wiring arrangements precluded feeding the automatic message sender with more than two channels simultaneously (see Figures 6 and 7) Two TDMS-5 and TDMS-6 Distortion Measuring Sets were on the aircraft and one set at Ava (see Figure 8). These were used most of the time to generate the test messages. For a S + N/N ratio of 8-10 db, 77 errors were observed in a total of 19,474 bits, that is, one error in 2.5×10^2 bits. As the S + N/N ratio increased to 12 db, the error rate reduced to 1 in 1.5×10^3 bits (202 errors in 305,739 bits). This may be considered acceptable for some clear test transmission, but is not acceptable for use with computers and similar devices.

At a signal-plus-noise/noise ratio of 15 db, from a total of 489,622 bits, 29 errors were observed for an error probability of 1 in 1.68×10^4. At a signal-plus-noise/noise ratio of 30 db, from a total of 118,811 bits, no errors were registered. A tabulation of the test results is included in the Appendix.

4. TEST RESULTS

All incorrect characters were counted as a one bit error. The actual number of errors noted may be slightly less since a mutilation of the stop element in the start-stop system can result in several successive printed errors inasmuch as the machine may require several characters to get back into synchronization. Errors are shown against both bits and characters transmitted. Each character is this case contained seven bits. It is common practice to display error rated in bits for data systems. The primary interest in error rates

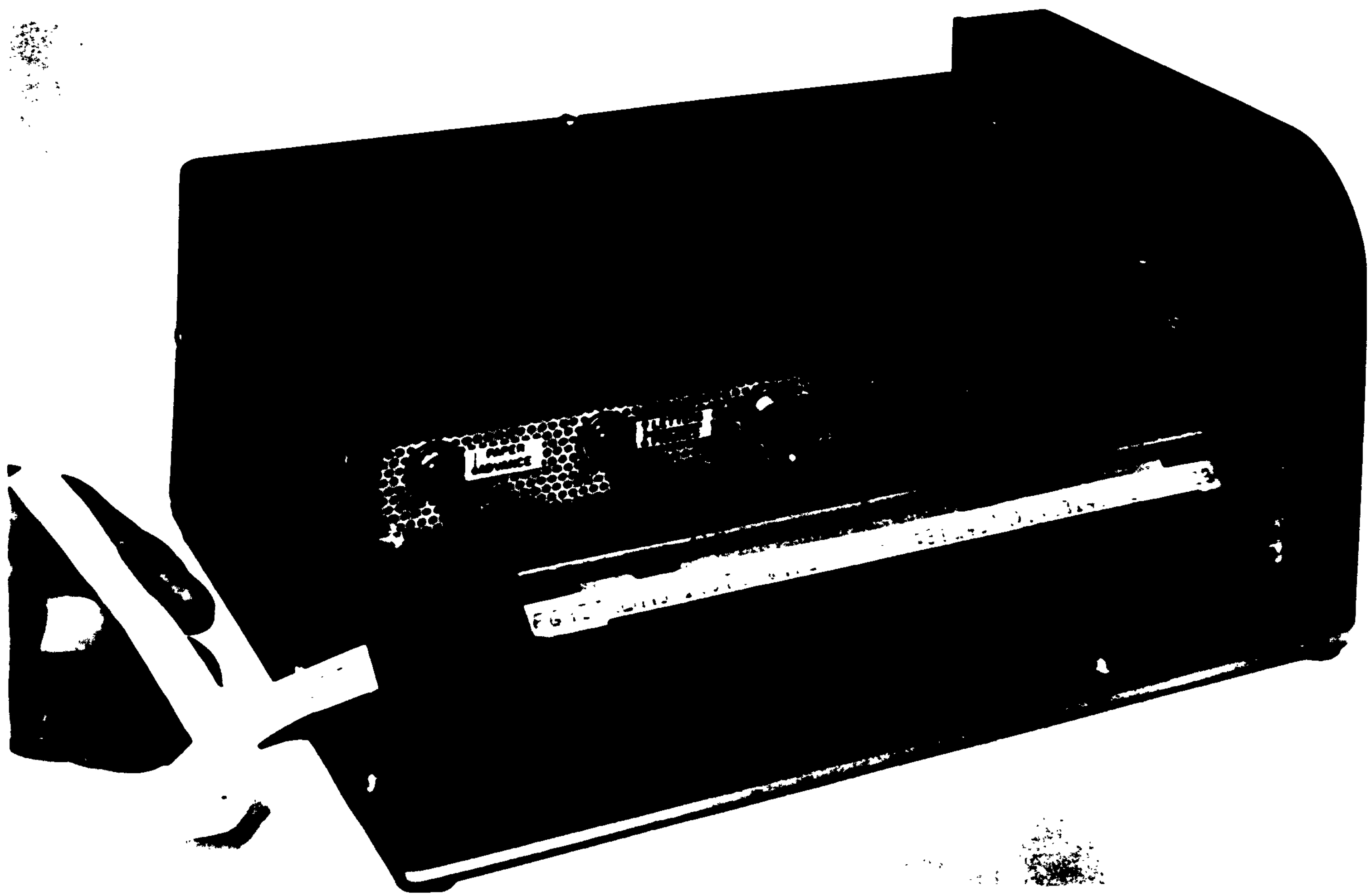


Figure 5. Goodyear Printer.

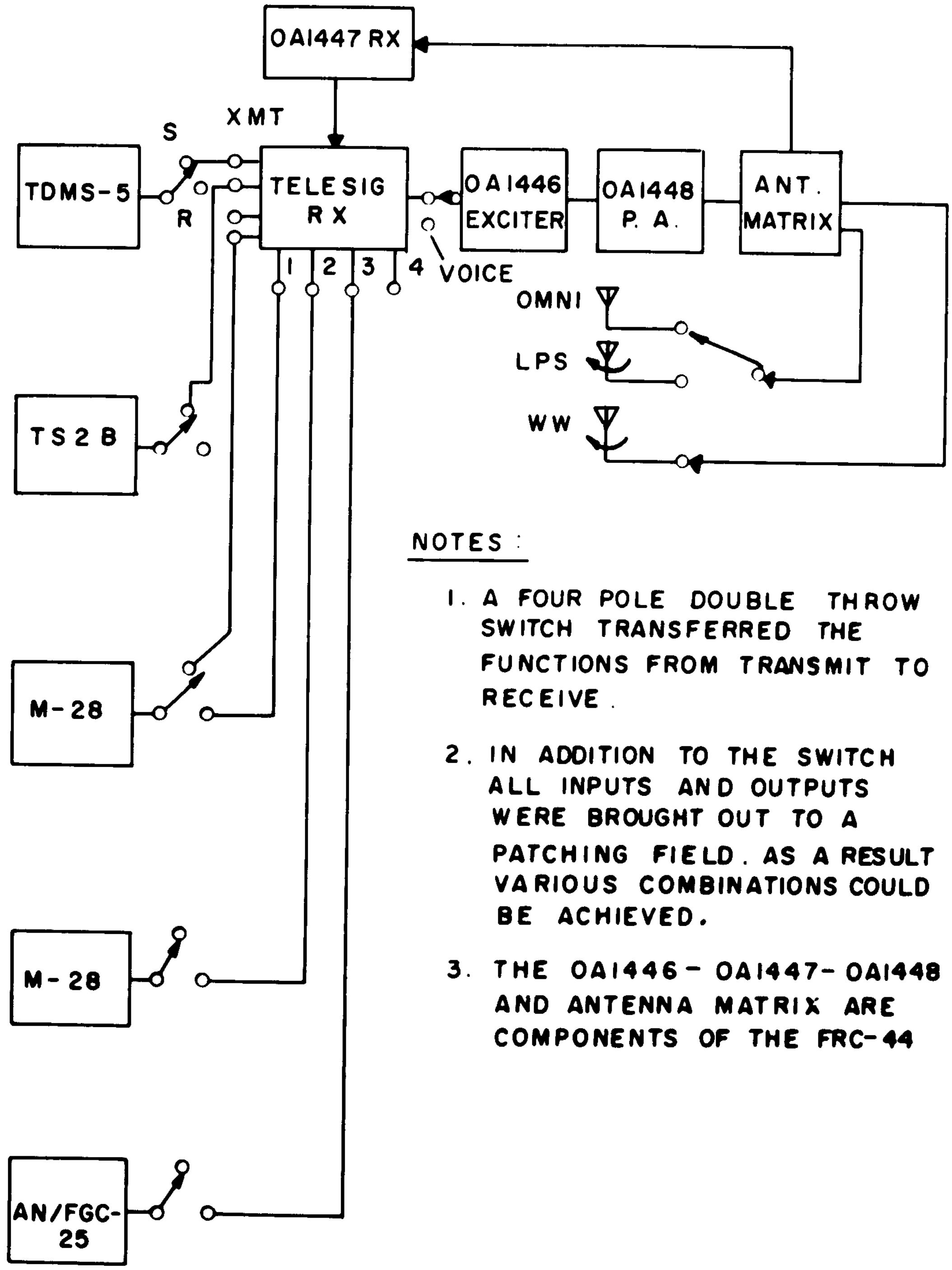
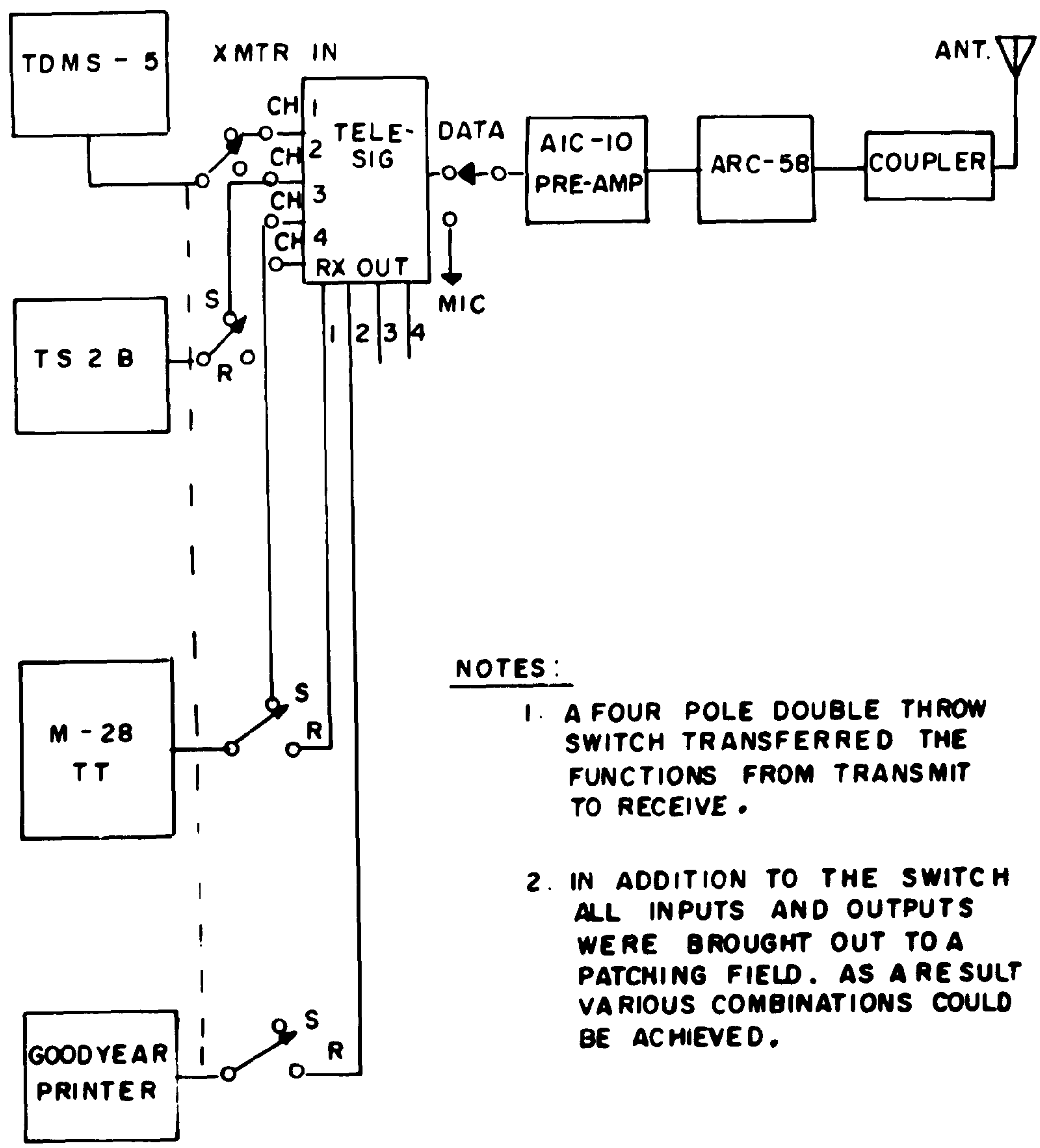


Figure 6. Block Diagram, Ava Site, Ground Station Test Layout.



NOTES:

1. A FOUR POLE DOUBLE THROW SWITCH TRANSFERRED THE FUNCTIONS FROM TRANSMIT TO RECEIVE.

2. IN ADDITION TO THE SWITCH ALL INPUTS AND OUTPUTS WERE BROUGHT OUT TO A PATCHING FIELD. AS A RESULT VARIOUS COMBINATIONS COULD BE ACHIEVED.

Figure 7. Block Diagram, Aircraft, Test Layout.

Radiation Equipment

Transmitter TDMS-5 | Receiver TDMS-6 | Tel-a-scan Model 14-200

Figure 8. Rack Mounted Power Supply with Equipment Plugged In. Power Supply Model 14 102.

which concerns operating people, however, for printed text is the number of errors in characters, words, groups, blocks, et cetera; hence, errors are also shown in terms of characters transmitted.

The start-stop teletype system used on these tests, being non-synchronous, will give a higher error rate. If the system is operated synchronously, such as on-line encryption, the decrease in error rate would be equivalent to a 3-db signal-plus-noise/noise improvement. Most of the errors observed during these tests were random in nature. A few were in groups or bursts, which is characteristic of most transmission systems. The error distribution is such that very low error rates could be achieved with the application of some of the better error-detection-and-correction techniques when the transmitted data must have very low error rates. A discussion of error detecting and error correcting can be found in the Bell System Technical Journal.[1,2,3] An uncorrected error rate of one in 1000 should be able to be reduced to as little as one in 100,000 with error detection and correction techniques applied.

The advantages of dual diversity on high frequency systems has been covered in the literature[4] and its use is essential for reliable operation of data transmission systems. Figure 9, taken from T.O. 31Z-10-1, Ground Telecommunication Performance Standards for Medium and High Frequency Communication, shows the improvement (in decibles vs probability of binary errors) using dual, triple and quadruple diversity.

The test results indicated that error rates are related to the signal-plus-noise/noise ratio in the 100 cycles-per-second bandwidth of each data channel as follows:

Signal-to-Noise	**8-10 db**	
16,576	64	
2,898	13	
19,474 bits	77 errors	1 in 2.5×10^2
Signal-to-Noise	**10 db**	
10,626	57	
57,960	80	
68,586 bits	137 errors	1 in 5×10^2
Signal-to-Noise	**11 db**	
47,250	218	
57,750	204	
51,450	152	
42,630	134	
62,475	128	
58,310	101	
319,865 bits	937 errors	1 in 3.4×10^2
Signal-to-Noise	**12 db**	
16,352	57	
14,973	24	
69,496	54	
64,582	32	
65,408	30	
74,928	5	
305,739 bits	202 errors	1 in 1.5×10^3
Signal-to-Noise	**15 db**	
4,921	0	
60,816	3	
57,820	1	
88,837	12	
71,708	5	
99,470	8	
106,050		
489,622 bits	29 errors	1 in 1.6×10^4
Signal-to-Noise	**30 db**	
58,016	0	
60,795	0	
118,811 bits		0 in 1.2×10^5

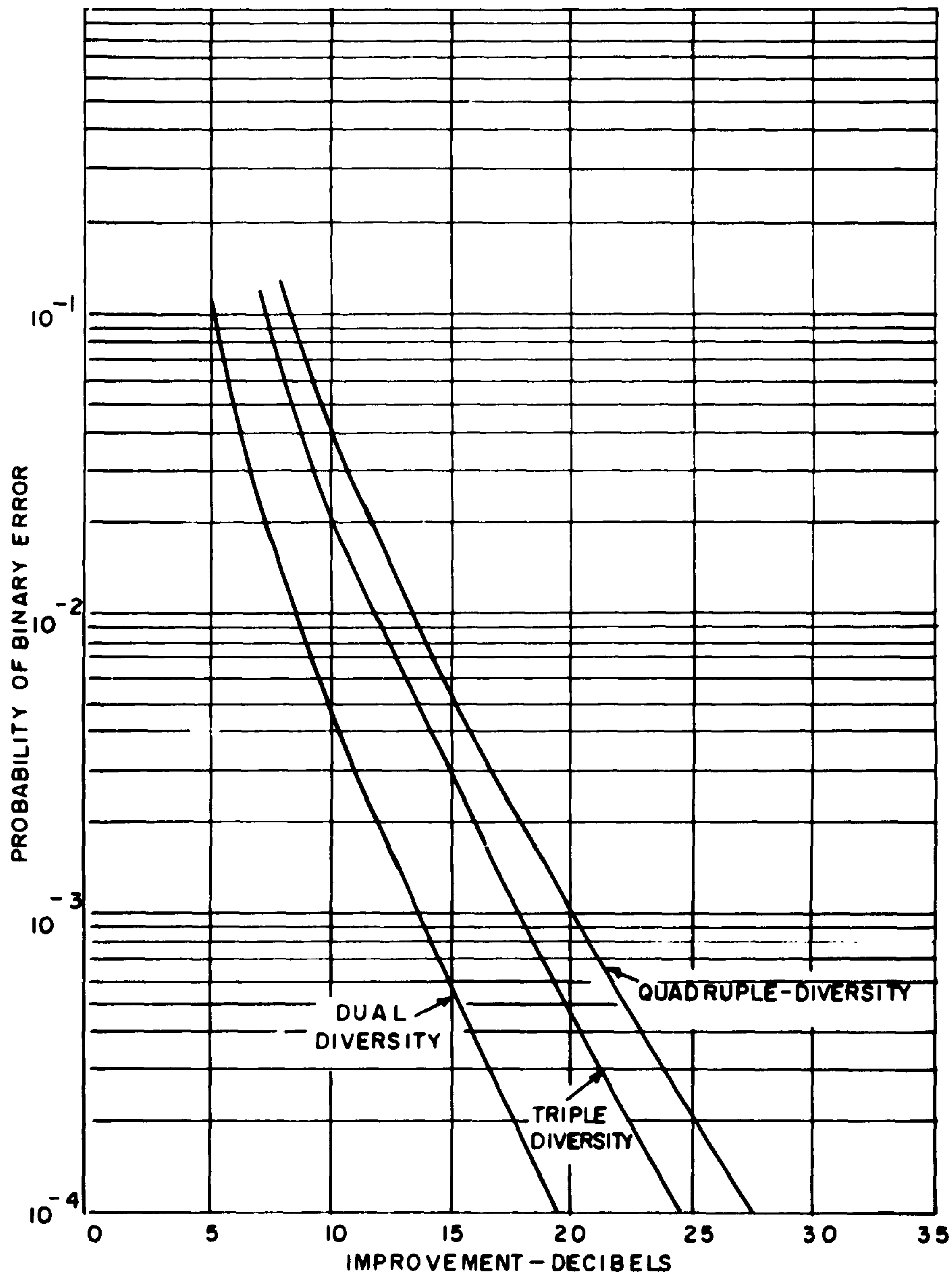


Figure 9. Probability of Binary Error vs Improvement - Decibel Curve.

5. CONCLUSIONS

Results of the tests indicate that the system performed satisfactorily in the presence of noise. Details of noise performance of narrowband frequency shift data systems will not be covered in detail in this report; mathematical analysis of these systems is adequately covered in the literature.[5] The system, as specified by contractor, normally provides error rates of approximately one in 2760 bits operating at a modulation rate of 74.2 bauds/sec with a signal-plus-noise/noise ratio of 10 db with a bandwidth of 100 cycles per second under laboratory test conditions. This figure assumes a Gaussian noise distribution and does not take into account impulse noise, which is frequently present in high frequency and other transmission mediums. Test data obtained with a 10 db S + S/N ratio showed an error rate of one in 5×10^2. This degradation can be attributed to the impulse noise.

Further, the system flight tested was operated non-synchronously. It has been shown elsewhere[6] that synchronous operation will give an improvement of 3.0 db. It can be concluded from the tests that doppler-correction, narrowband techniques and frequency diversity operation, when applied to ground/air/ground data transmission, has reliability and error rates equivalent to ground point-to-point systems operating within similar effective power ranges and antenna gains.

6. RECOMMENDATIONS

Based on the test results, the following recommendations are made:

a. The addition of error-detection-and-correction techniques and increased power should produce error rates low enough for most applications.

b. The doppler correction used for the test system used a low-level pilot tone. For practical application of the system, two of the data channel tones should be used to provide diversity operation and a higher "capture" rate. Where large amounts of doppler are present, several channels can be used to "sense" the amount of initial correction necessary. The doppler correction unit should be so designed that no manual adjustments are necessary during normal operation of the equipment.

c. Additionally, the doppler-correcting device incorporated a long time delay for the purpose of retaining memory control during short periods of complete fade-out of the control signal. Also this feature permitted operation at signal-to-noise ratios too small for normal satisfactory data transmission. Some long term drift of the automatic frequency control unit was encountered, This is a minor design problem that should be corrected.

d. It is also recommended that, for convenience in packaging, the doppler correction should be controlled from the outside channels of a basic four-channel system with a switching arrangement to shift the doppler sensing device to the outside channels of an eight-channel system. The four-channel arrangement is suitable for limited-bandwidth radio-frequency systems such as the AN/ARC-58. To utilize a full eight channels, the radio-frequency equipment must have a bandpass response from 350 cps to 3040 cps. The ripple between 350 and 3040 cps should be less than ±1.5 db for reliable performance.

REFERENCES

1. "Error Detecting and Error Correcting Codes," The Bell System Technical Journal, Apr 1950, p 147.

2. "Recurrent Codes: Easily Mechanized Burst-Correcting, Binary Codes," The Bell System Technical Journal, Jul 1959, p 969.

3. "Capabilities of Telephone Networks for Data Transmission," The Bell System Technical Journal, May 1960, p 431.

4. Diversity: Combining Techniques, IRE Proc., Jun 1959, p 1075.

5. Montgomery, G.F., "Comparison of Amplitude and Angle Modulation for Narrow Band Communication of Binary Communication Messages in Fluctuating Noise," IRE Proc., Vol 42-2, Feb 1954.

6. Lawton, J.G., "Theoretical Comparison of Binary Data Transmission Systems," RADC-TR-58-91, AD 148803, p 23.

APPENDIX

DATA TABULATION

1. RADC Ava Site Receiving using M-28 Teletypewriter - Air to Ground.
2. Aircraft Receiving using M-28 and Goodyear Teletypewriter - Ground to Air.
3. RADC Ava Site Receiving using M-28 Teletypewriter - Air to Ground - Aircraft enroute Travis AFB to GAFB.
4. Ava to Aircraft using Teleprinter M-28 and Goodyear Solid State Unit. Enroute Griffiss AFB - Travis AFB - Griffiss AFB.
5. Notes.
6. General Comments.

1. RADC AVA SITE RECEIVING M-28 TELEPRINTERS AIR TO GROUND

DATE	EDT TIME	RADIO FREQ.	CHANNEL	CHARACTERS	BITS	ERRORS	NOTES	REMARKS
1 May 62	0940	23325		3140	21,980	0		
		13210		402	2,814	6		
		13210		670	4,690	12		
2 May 62	1931	11216	1	385	2,695	17		Keyboard Sending
	1931	11216	2	1005	7,035	22		S/N 5-6 db QRM from 11228 kc
	2035	6756		Junk			6	Lost contact
	2310	6756		282	1,974	1		
3 May 62	2108	13210		792	5,544	14		S/N 5-6 db - repeat errors, may be partly TDNS Auto.
	2215	13210		703	4,921	0		S/N 15 db keyborad
	2255	13210		8688	60,816	3		S/N 15 db TDNS Auto.
	2345	13210		8260	57,820	1		S/N 15 db
		13210		12691	88,837	12		S/N 15 db
		13210		10244	71,708	5		S/N 15 db
4 May 62	0035	9022	3	2368	16,576	64		S/N 8-10 db heavy fading TDMS auto
	0035	9022	4	414	2,898	13	6	Last half garbled-lost radio contact at 0100
		13210	2	Approx. 4 errors per line			6	S/N 5-6 db

2. AIRCRAFT RECEIVING M-28 AND GOODYEAR TELEPRINTERS GROUND TO AIR

DATE	EDT TIME	RADIO FREQ.	CHANNEL	CHARACTERS	BITS	ERRORS	NOTES	REMARKS
1 May 62		23325		5251	36,757	0	4	M-28
		13210		2500	17,500	100	1,4	M-28
		13210		4248	29,736	40	4	M-28
	1425	13210	1	5040	35,280	2	4	Goodyear
	1425	13210		7670	53,690	27	4	M-28
	1448	13210	1	1715	12,005	3	4	Goodyear
		11216		362	2,534	0	4	M-28
		15093		3254	22,778	20	5	M-28
		11216		9499	66,493	350	5	M-28
2 May 62	0347	6756	1	441	3,087	1		M-28
	0435	4748		Broken Up			1	M-28
	1321						2	
	1552	13210	3	2145	15,015	1		M-28
	1845	15093	4	1462	10,234	0		M-28
	2135	11230		1071	7,497	1		M-28
	2157	11230		4410	30,870	25		MB-28
		11216		5304	37,128	142		Goodyear
		11216		6809	47,663	97		Goodyear
		11216		5760	40,320	50% Approx Character errors		Goodyear
3 May 62	0003	11216	4	2241	15,687	70		M-28
	0123	11216	4	1008	7,056	16		M-28
	0123	11216	1	4977	34,839	80		M-28
		(chg to)						
	2345	11216	4	2067	14,469	5		M-28
	2355	11216	3	3969	27,783	4		M-28
		13210		4470	31,290	141		Goodyear
4 May62	0009	9022	2	5418	37,926	5		M-28
	0038	9022	2	1890	13,230	2		M-28
	0040		3	Junk			1,3	M-28
	0045		4	567	3,969	10% appr	1,3	M-28
		15093		833	5,831	41		Goodyear
		15093		2090	14,630	70		Goodyear
		15093		3128	21,896	93		Goodyear
5May62	1645	15093	3	3024	21,168	11		Goodyear
	1900	15093	3	3960	27,720	11		Goodyear
	1925	15093	3	3780	16,460	18		Goodyear
6May62		11216	3	1438	10,066	3		Goodyear
		9022	1	2516	17,612	1		Goodyear

3. RADC AVA SITE RECEIVING M-28 TELEPRINTERS AIR TO GROUND ENROUTE TRAVIS AFB TO GRIFFISS AFB

DATE	EDT TIME	RADIO FREQ.	CHANNEL	CHARACTERS	BITS	ERRORS	NOTES	REMARKS
12Jun62	1653	15,093	2	8,288	58,016	0		S/N 30 db (using TDMS Sender)
	1653	15,093	4	8,685	60,795	0		S/N 30 db 2B Sender
	1803	11,216	2	14,210	99,470	7		S/N 15-20 db 2B Sender
	1803	11,216	4	15,150	106,050	1		S/N 15-20 db (using TDMS Sender)
	1950	15,093	2	6,750	47,250	218	9	S/N 10-12 db using 2B Sender
	1950	15,093	4	8,250	57,750	204	9	S/N 10-12 db (using TDMS Sender)
	2139	17,075	2	7,350	51,450	154	9	S/N 10-12 db (using TDMS sender)
	2139	17,075	4	6,090	42,630	139	9	S/N 10-12 db (using 2B Sender)
	2200	17,075	2	8,925	62,475	128	9	S/N 10-12 db (using TDMS Sender)
	2200	17,075	4	8,330	58,310	101	9	S/N 10-12 db (using 2B Sender)
13Jun62	2220	17,075	4				1,9	S/N 8-10 db errors greater than 4 in 100 characters-QRM
	2220	17,075	2				1,9	Same as Ch.4
	2308	15,093	4				1.9	Same as above S/N 8 db
	2308	15,093	2				1,9	Same as above S/N 8 db
	2318	15,093	1				1,9	Heavy QRM on this Ch.S/N 10 db
	2318	15,093	2	1,518	10,626	57		S/N 10 db, QRM
	0037	11,216	2	8,280	57,960	80	9	S/N 10 db Intermittent QRM
	0037	11,216	4				10	TDMS Message Sender failed
	0115	11,216	3	2,336	16,352	57	9	S/N 12 db (using TDMS Sender)
	0115	11,216	4	2,139	14,973	24	9	S/N 12 db (using 2B Sender)
	0130	11,216	3	9,928	69,496	54	9	S/N 12 db (using TDMS Sender)
	0130	11,216	4	9,226	64,582	32	9	S/N 12 db (using 2B Sender)
	0215	11,216	3	9,344	65,408	30		S/N 15db (using TDMS Sender)
	0215	11,216	5	10,704	74,928	5		S/N 15 db (using 2B Sender)

4. AVA TO AIRCRAFT TELEPRINTERS M-28 AND GOODYEAR ENROUTE GRIFFISS AFB - TRAVIS - GRIFFISS AFB

DATE	EDT TIME	RADIO FREQ.	CHANNEL	CHARACTERS	BITS	ERRORS	NOTES	REMARKS
12Jun62	1715	15,093	1	2,016	14,112	22		Goodyear Teleprinter
	2245	17,075	2,4	2,016			7,8	Unsatisfactory - M-28 operation
	1910	11,216	2	1,323	9,261	111		Goodyear Teleprinter
	1910	11,216	4				7,8	Unsatisfactory - M-28 operation
14Jun62	0100	11,216	3	3,337	23,359	2		Goodyear Teleprinter
	0100	11,216	4				7,8	M-28 Teleprinter in trouble
13Jun62	2155	11,216	2	4,352	30,464	109	7,8	M-23 malfunctioned
			4	3,456	24,192	6		Goodyear Teleprinter

5. NOTES (As referenced in tabulated test results under Column 8)

a. Heavy interference on the frequency in use. Noise and Carrier/Telegraph was often present, in addition to AM carriers, multiplex, etc.

b. Aircraft in testing their system back-to-back found the TDMS-5 automatic message unit was sending garbled test. Two units were on the aircraft and both malfunctioned. The second unit introduced added characters which were fairly consistent, but the output contained high distortion which accounts for some of the poor transmission from aircraft to ground.

c. Worn tape on the transmitter-distributor at Ava Test Site caused distortion.

d. Aircraft enroute Griffiss AFB to Travis AFB.

e. Aircraft enroute Travis AFB to Eielson AFB. Air-to-ground communication lost, but the aircraft was receiving continuously as high power was being transmitted from the Ava Ground Station.

f. The most serious limitation on the air-to-ground transmission is the power capability of the AN/ARC-58. The transmitter is designed for an intermittent duty cycle with maximum peak envelope power (PEP) of 1000 watts. When using continuous multi-tone loading the power must be limited to 400 watts (PEP). Under this condition the aggregate power with tones on is less than 100 watts. The actual radiated energy is further reduced by the inefficient aircraft antenna. Much of the time, signal-plus-noise to noise ratio was 5 db, except on 3 May 62 when the signal-plus-noise to noise increased to 12-15 db and fairly low error rates were achieved. It is expected that nearly all air-to-ground transmission would be acceptable if the aircraft had a peak envelope power of 5 kw. It was noted on the good transmission of 3 May 62 that although signal strength was substantially improved, that Auroral "flutter" at a rate of 5-10 cycles per second was present. Interrupting the diversity channel during this period resulted in completely garbled copy, which indicates that the diversity combiner used had excellent high speed operation. The signal-to-noise ratio was measured at the start of each transmission. One tone was removed at the start to measure the noise at the output of the channel filter. The tone was then restored and the tone level measured.

g. After the trip was completed it was found that metal shavings in the M-28 teleprinter mechanism was causing malfunction. This apparently occurred accidently when additional equipment was mounted above the M-28 after the first trip was completed.

h. Signal-to-noise measurements were not made aboard the aircraft due to shortage of operating personnel on the second trip. This data is shown only for informational purposes.

i. Poor signal-to-noise and heavy interference on the frequency. The optimum frequency was not always available due to heavy interference.

j. Considerable trouble was experienced with the TDMS-5 automatic message sender on the aircraft. At times, the pattern keys were used with fair reliability. On the last trip a Test Set 2B/TG mechanical automatic sender was added to the TDMS-5 in the aircraft. It should be noted that errors on the channel using the 2B Test Set were less than half of those using the TDMS-5..

6. GENERAL COMMENTS

In addition, S + N/N ratios on the majority of aircraft transmissions were less than 15 db. An increase of 10 db in aircraft transmitting power would result in a similar increase in signal-to-noise ratio at the ground station. With the ground antennas used for these tests, the error rates would become negligible for over 90 percent of all transmission periods. The aircraft power to provide this improvement would be 4-5 kw Peak Envelope Power, assuming the use of the antenna system presently used on the KC-135 aircraft. The aircraft antenna consisted of a long wire from approximately 20 feet back of the nose section to a position approximately ten feet below the top of the tail section. The first flight utilized an insulator at the tail junction. On the second flight the wire was directly connected to the tail section forming a one turn loop through the fuselage of the aircraft. No specific signal strength comparisons were made between the two arrangements. Both performed satisfactorily. The loop arrangement could have lower maximum-voltage points, which may be advantageous on high altitude aircraft. Further investigation is required.

For practical application the receiving station should provided be with high gain directional antennas where feasible. A substantial improvement can be obtained in this area. It is also advisable that the antenna have as few multiple lobes as possible. The ground transmitter should also have directional antenna systems to minimize multipath. Equivalent gain, however, can be obtained with increased power at the ground station.

It was noted in the test aircraft that noise in the audio circuits from the 400-cycle power supply and other sources was present to a higher level than desired. Precautions in installations should be closely maintained. Two such precautions are balanced audio circuits and insulated triple-shielded twisted pair wiring. Careful grounding of the shields is important to prevent ground loops. The electronic equipment should also be immune to high external magnetic fields.

It is evident from experience with the tests that data operation to and from high speed aircraft creates operational problems which are not present in other types of operation. At the speed of KC-135 aircraft, the duration of transmission periods on an optimum frequency becomes quite short compared to point-to-point ground operation and other types of ground/air operation. It is important that the equipment on the ground and in the aircraft be capable of changing channels rapidly to avoid lost time. Ideally this change should be made in not more than 2-5 seconds

Data transmission was satisfactory while the aircraft was on the ground at the refueling locations both in Seattle and at Eielson AFB. This indicates that the system can be used as a temporary ground point-to-point system.